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RESEARCH ISSUES IN POWER CONDITIONING: A WORKSHOP HELD  
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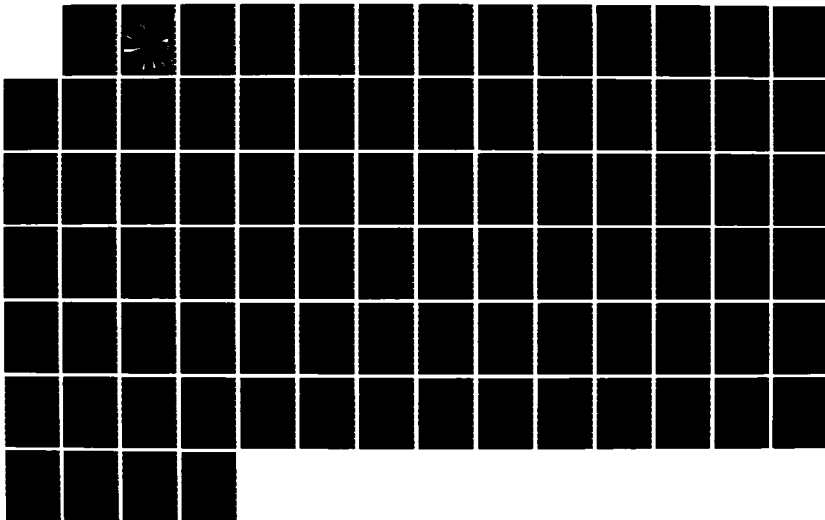
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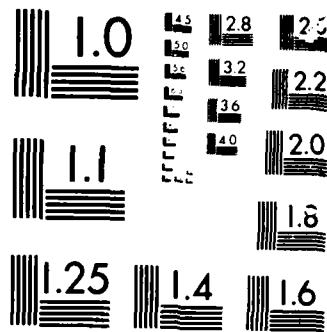
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# Issues in Power Conditioning

A workshop held at the University of Southern California

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The workshop was organized to address a problem that has arisen in the area of pulsed power, or power conditioning research. The problem is the development of a gap between applied physics research that deals with fundamental device physics, and the development of improved pulsed power devices. The purpose of the workshop was to work to change an impedance mismatch, and foster communication between research and pulsed power engineering.		

# RESEARCH ISSUES IN POWER CONDITIONING

A Workshop held at  
The University of Southern California

Los Angeles, California 90089-0484  
December 3<sup>rd</sup> and 4<sup>th</sup>, 1985

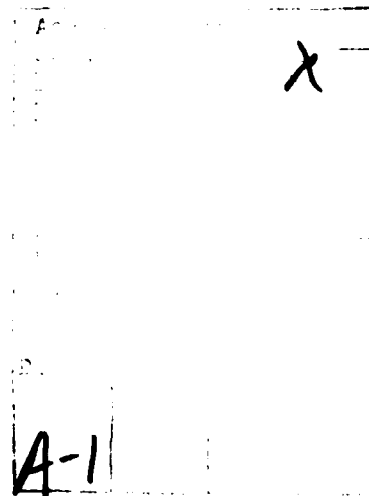


## Organizing Committee:

Martin Gundersen, University of Southern California, Chairman  
Robert DeWitt, Naval Surface Weapons Center  
C. Randol Jones, Los Alamos National Laboratory  
Joseph Kunc, University of Southern California  
Gerhard Schaefer, Texas Tech University

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## RESEARCH ISSUES IN POWER CONDITIONING

Martin Gundersen - Technical Chairman  
Lawrence Luessen - Administrative Organizer

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Attention: Ms. Sarah G. Novak  
University of Southern California  
Los Angeles, CA 90089-0484

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P.O. Box 1163  
MS J 566  
Los Alamos, NM 87544

The Naval Surface Weapons Center  
Code F 12  
Dahlgren, VA 22448

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I would like to acknowledge the help of a number of important people. The members of the organizing committee undertook a great deal of work, and were extremely responsive. The attendees were very generous with their time and energy, and are greatly appreciated. The support of the funding agencies, and the encouragement of Bob Guenther, Henry Pugh and Bruce Smith are gratefully acknowledged. I would also like to thank Sarah Novak, Rosalinda Senaha, and Roberta Gundersen.

## **COMMITTEES**

### **1. High Power and Moderate Power Lasers**

**M. Kushner, G. Schaefer, A.H. Bushnell, L. Christophorou,  
H. Grunwald, J.E. Lawler, D. Lorents, P.N. Mace, G. McDuff,  
S. Schneider, R.W. Schumacher, S. Srivastava, D.V. Turnquist**

### **2. Microwaves and EMP/Simulation**

**P.F. Williams, C.R. Jones, G. Frazier, M. Heyne,  
E.E. Kunhardt, A. Ramrus, K. Schoenbach, J. Stover**

### **3. EM Launchers**

**R. DeWitt, R. Askew, R.A. Dougal, L. Hatfield, J. Hyman,  
F. Rose, C. Thio**

### **4. Magnetic Fusion**

**J.A. Kunc, W. Byszewski, D. Huttar, H. Kuehl, L. Laghari,  
P. Rock**

### **5. Particle Beams**

**A.K. Hyder, E.P. Muntz, T. Burkes, M.T. Buttram,  
A. Chutjian, C. Huddleston, I. Katz, L.C. Lee, K. Whitham**

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## INTRODUCTION

The Workshop on Research Issues in Power Conditioning was organized to address a problem that has arisen in the area of pulsed power, or power conditioning, research. The problem is the development of a gap between applied physics research that deals with fundamental device physics, and the development of improved pulsed power devices, such as high power switches. Thus the purpose of the workshop was to work to change an 'impedance mismatch', and foster communication between research and pulsed power engineering. Attendees represented universities, industry, and government including laboratories, funding agencies, and the White House and Congressional science and technology offices.

In order to accomplish this it is necessary to identify research that supports power conditioning technology. The workshop did this by dividing into groups according to applications, each group including a mix of engineers and scientists. The applications included lasers, launchers, particle beams, microwaves, simulation, and magnetic fusion.

The committees were asked to define research needs in terms of quantitative data, numbers or other measurables, the boundaries or limits to existing theories and knowledge, and specifically what should be studied. In this way, research needs were considered in the context of the specific applications.

The chapters of this report are organized according to these applications, and each chapter was prepared by the specific applications committee. Each of these chapters includes an introduction and a summary of perceived research needs, with separate information that describes each research topic.

### PRESENTATIONS

The workshop was composed of participants with considerable expertise in research and

engineering, with the result that very few formal presentations were necessary. The talks that were given served to highlight especially important current issues. Although written summaries of these talks were felt to be inappropriate for the report, which is basically a summary of recommendations, a brief discussion of each talk is presented below, to characterize their role in the workshop.

In an introductory talk, William Spitzer provided information about the role of basic research in the development of solid state device technology. Tracing the transition from fundamental to applied research and development, Dr. Spitzer demonstrated the essential role of research in the development of this now mature technology -- providing an important analogy to the present need for research in power conditioning.

In an incisive overview, Richard Verga discussed the research implications of the new technology that is needed for space power systems. Technology areas included inductive energy storage, opening switches, thyratrons, spark gaps, magnetic switching, solid state switches, RF, inverters, alternators and transformers, flashover, and capacitor development. Dr. Verga reviewed 98 different areas where research is necessary, providing a coherent, integrated concept of research and development for space power.

The workshop focused on power conditioning, and did not develop recommendations for prime power. However, in order to define the context within which power conditioning issues must be considered, Sydney Singer presented a discussion of prime power issues, providing material with important implications for the development of solutions to pulse power/power conditioning problems.

Len Caveny and Frank Rose presented a discussion of SDI research issues. Dr. Rose also discussed the role of the Power Consortium, and

## INTRODUCTION

described basic issues where the solution will make a difference for pulsed power applications.

An overview of limitations in power conditioning was presented by Tom R. Burkes. This presentation reviewed the role of various technologies in terms of switch limitations, materials needs, and pulse requirements for energy transfer. With the benefit of Dr. Burkes broad knowledge, this review provided a focus, as the workshop separated into smaller groups.

## RECOMMENDATIONS

Although specific recommendations are detailed in the other chapters, in this section some general recommendations are presented. These are typically recommendations which are common to several committees. While some of these deal with specific research topics, others involve organizational issues, such as mechanisms for improving communication within the pulsed power/power conditioning community. Tables I and II summarize these recommendations.

There were several recurrent themes. The most common is summarized in the following quote from the Laser Committee, written by Mark Kushner and Gerhard Schaefer:

"In spite of the diversity of research topics determined by this committee to be crucial to present and future pulse power technology development, a recurrent theme surfaces: *Technology development must be preceded by a commitment to basic research.* Pulse power technology development has traditionally lacked this commitment, due in part to the "hardware" orientation of pulsed power and due in part to the lack of basic research tools. This latter cause has been somewhat tempered during the last few years as a result of advances in both experimental diagnostics and theoretical modeling... In the discussion for every topic "(in order to provide sources for new technology)", the need for basic, long term measurements and modeling was stressed time and time again."

RECOMMENDATION AREA	COMMENTS
Interactions between related conferences	A formal mechanism should be established that will foster interactions between traditional pulsed power meetings and conferences including the Gaseous Electronics Conference the International Quantum Electronics Conference, and the Conference on Lasers and Electro-Optics
Communication of research results	1. Establish a bimonthly pulsed power newsletter 2. Encourage publication in refereed journals
Encourage graduate education	This will develop the basic research capability, and provide new sources of fresh ideas
Long term funding	Long term funding is necessary for the development of a strong research community -- both through the development of a vastly improved research capability, and for the education of students of the highest calibre

TABLE I. General recommendations for improved communication between research and development.

It may be readily ascertained that a commitment to research has preceded essentially all of the important technological developments during the last century, *including the development of pulsed power technology that occurred during the first half of this century.* Nevertheless, for the last twenty five years, the basic research component that has been so important in areas such as lasers, solid state devices, and semiconductor materials, has been limited or lacking within the pulse power community.

RECOMMENDATION AREA	COMMENTS
Switches	Most common concern. Areas include solid state switches, discharge physics, cathode physics, basic research that supports the generation of new ideas
Dielectrics and insulators	New materials, physics pertaining to materials
Interfaces and surfaces	Physical processes affecting electrical breakdown, materials

TABLE II. The three most common areas for research problems. It may be noted that within each of these areas there are several sub-areas, or fields of research. Thus within switches there is research needed in solid state devices, solid state physics, surface-plasma interactions, optical interactions with gases and solids, discharge physics, electrical breakdown, gas discharge devices, and others. It was apparent in the workshop that there is a general tendency in the power conditioning community not to recognize this wide diversity of problems that are associated with device research.

The effects of the lack of a basic research component that is integrated into device development may be seen in other areas. For example, in the area of high power laser development, the basic problem is often misunderstood -- both by the laser community, and the power conditioning community. The development of high power lasers is generally considered to be comprised of two separate problems -- rather than one. The first is the invention of a laser by a scientist, who uses physical insight to find a new mechanism to obtain inversion, and hence a new laser. The second is the development of the laser by an engineer, who is asked to scale the laser to higher power. Except for some rather unusual examples, this is the procedure that is ordinarily followed.

This view is incorrect, and one result of this view is that most existing large lasers are not very practical. Nevertheless the amount of resources that are directed towards scaling is large compared to that directed towards developing new ideas.

The development of high power lasers is actually a problem that requires a basic view throughout -- so that scaling also is recognized as needing new ideas based on physical insight and new mechanisms, and is integrated with the physics of the laser. These problems are interrelated. Lasers are needed that are *a priori* scalable, and funds that are expended on the scaling of an impracticable laser would be put to better use if directed toward the development of new ideas that are scalable. Research should address fundamental problems *and* the improvement of the performance of the laser.

A similar situation exists for the development of a new generation of high power switches. The basic researcher is often willing to look into the physics of a particular process associated with a switch or new switch idea -- sometimes with an appalling lack of consideration for the practicability of the switch idea. Similarly, the applications-oriented engineer or systems engineer often expects to be able to use the first available candidate. Detailed examples of basic research that is needed for switches are abundant in the text of the report including problems in cathode and discharge physics, high temperature dielectrics, and diagnostics. However, it is important to seed new ideas that bear on improving high power switches, *and* that address basic research issues.

Pulsed power needs good basic researchers as well as dedicated, high quality engineers. However, what is also needed is a community that is capable of taking a balanced look at issues and ideas -- both in terms of physics, and applications.

## **Section I**

# **Report of the HIGH POWER and MODERATE POWER LASERS COMMITTEE**

**Mark Kushner and Gerhard Schaefer, co-chairmen**

# HIGH POWER and MODERATE POWER LASERS

## Committee members:

M.J. Kushner, G. Schaefer (chairmen),  
A.H. Bushnell, L. Christophorou, H.  
Grunwald, J.E. Lawler, D. Lorents, P.N. Mace,  
G. McDuff, S. Schneider, R.W. Schumacher,  
S. Srivastava, D.V. Turnquist

## SUMMARY

The High Power and Moderate Laser Committee examined those pulse power issues important to increasing the reliability, efficiency, and scalability of discharge, e-beam, and free electron lasers. The discussion was wide ranging since pulse power impacts moderate and high power lasers in every aspect of their operation; from primary power to laser cavity materials. To limit the discussion to a manageable number of topics, prime power and ancillary systems (e.g. gas clean up and flow) were not considered. The pulse power systems included in the discussion were power conversion (primary to secondary), power conditioning (secondary to PFN), transition section (PFN to laser cavity), pre-ionization, and electrical aspects of the laser cavity itself. A total of 25 topics (and 33 additional sub-topics) were identified as being worthy of additional consideration. Due to the large number of topics, we attempted to extract from the list a subset of common issues which were more "generic" in character. These "generic", but specific recommendations, are those which we determined to have the highest leverage; that is topics on which research will benefit the widest range of problems currently faced in the development of moderate and high power lasers. These topics, listed in their order of importance (with "ties" shown), are

1. a. Dielectric Interfaces and Surfaces
  - b. High Current Discharges (Thyratrons and Crossatrons)
2. a. Cold Cathodes
  - b. High Temperature Solid and Gas Dielectrics
  - c. Diffuse Discharges (Opening Switches)
  - d. Diagnostics
3. DC-DC Power Conversion

Each of these topics will be discussed in more detail below.

### Dielectric Interfaces and Surfaces:

In every area of pulse power discussed for moderate and high power lasers, dielectric interfaces (from solid to solid, liquid, gas, and vacuum) and breakdown along surfaces were deemed important research topics. The use of dielectrics as insulators in high voltage systems are at best only empirically understood. This committee recommends that basic research be performed to establish a data base which enables dielectric surfaces to be characterized in much the same fashion that gaseous dielectrics are. For example, surface charge multiplication could be characterized by a cross section analogous to the ionization cross section of a gas. The basic transient processes leading to breakdown near surfaces must also be addressed (e.g. adsorption, desorption, recombination, secondary emission) in a systematic fashion. These processes also include the modification of local electric fields by charge accumulation on the surface. Since dielectrics react with their environment either chemically or by radiation, thereby changing their properties, the aging phenomenon of dielectrics must be investigated. Dielectrics can also play an important "passive" role with respect to discharge chemistry by acting as a catalyst for processes such as surface ionization.

### High Current Discharges:

The physics of high current discharges for conventional applications are well understood. The switches required for moderate and high

power lasers (thyatrons and crossatrons), though, utilize high current discharges under conditions where these partially or highly ionized plasmas are not well understood. This lack of understanding has impeded the development of said switches. The committee recommends that high current discharges, as applied to low pressure plasma switches, be a specialized topic of research. We differentiate these discharges from other discharges by describing them as being geometrically "bounded" plasmas. The characteristics of a high current plasma flowing through, say, the control grid slot of a thyatron differ greatly from a plasma flowing in an unbounded space. We identified the approach to plasma pinch conditions in complex geometries, transient instabilities (grid spot hopping), and gas pumping in thyatron-like switches as particularly important research topics. The difference between short pulse and long pulse characteristics should also be examined. Both experiment and theory should be pursued. We emphasize the necessity to "iterate" between theory and experiment in this research topic to maximize the contributions of both areas.

#### Cold Cathodes:

Non-incandescent (i.e. cold) cathodes capable of electron emission with high current densities are important with respect to e-beam sources, thyatrons, crossatrons, and other electron emitting applications. Cold cathodes are attractive due to their insensitivity to contaminations as compared to oxide cathodes, "instant" start capability, and the absence of expensive standby heater power. Basic research in cold cathode development is necessary in two generic areas; surface and bulk mechanisms. In the surface area, the basic mechanism of electron emission must be better understood in order to enable the engineering of cathodes with energetically less expensive modes of emission (e.g. lower forward voltage drop, higher secondary electron emission). The range of candidate cathode surface materials must be quantitatively characterized, both experimentally

and theoretically. With respect to the bulk, the mobility and transport of low work function materials towards the surface (such as differentiation of processes under transient and steady state conditions) must also be addressed.

#### High Temperature Solid and Gas Dielectrics:

High temperature solid dielectrics are important in high average power applications and for use in magnetic switches where compatibility with the annealing process is required. These solid dielectrics must be mechanically flexible and have high dielectric strength. This committee deems such dielectrics as an important research area. We coined the expression "molecular engineering" to describe our desire to be able to fabricate dielectrics to meet specific requirements (e.g. graded dielectrics). High temperature gaseous dielectrics are also an important research topic with respect to their use in high current discharges (e.g. spark gaps). It is well known that the properties of gaseous dielectrics are a function of the gas temperature; the precise processes and manner of degradation or improvement of dielectric strength, and its long term stability, are not known.

#### Diffuse Discharge Opening Switches:

The importance of diffuse discharges with respect to pulse power for moderate and high power lasers lies not only in excitation of the laser gas mixture but also in their use for opening switches. For example, implementation of inductive high density energy storage for high peak power lasers requires an opening switch. Two generic areas of important research topics for diffuse discharges for opening switches are identified: extrinsic and intrinsic properties. Extrinsic properties include topics such as the generation of small volume, intense ( $10^4$ - $10^5$  Gauss), uniform magnetic fields for application to cross field devices. Intrinsic processes include those issues important to sustaining or interrupting the gas discharge. These would include the selection of gas mixtures, their discharge properties, and their lifetimes.

Alternate mechanisms for interrupting or controlling the discharge current must also be investigated, some of which are optical (e.g. opto-galvanic, optically sustained) and e-beam sustained discharges in conjunction with gas engineering.

#### Diagnostics:

Many pulse power systems for moderate and high power lasers require their use in remote terrestrial locations or in space where maintenance cannot be performed. Additionally, these pulse power systems must be at ready status for many years. The problem is that one desires to know the operational status of the system without performing an actual full power test of the device. This committee recommends that basic research be performed on passive diagnostic techniques capable of determining the physical state of a system without performing a full power test. For example, the degradation in the dielectric strength of an insulate might be determined by chemical or spectroscopic analysis of its surface or of its local environment. Low current/voltage tests may also be appropriate. The basics of conventional diagnostics must also be addressed; particularly the measurement of transient high voltages in the absence of a reference (i.e. ground). Finally, the interfacing of many complex pulse power systems, as envisioned by the SDIO, requires an agreed upon set of standards and calibrations.

#### DC-DC Power Conversion:

This mode of power conversion is important at the interface of the primary power source to the initial stage of power conditioning. Efficient high frequency inverters must be developed, both solid state and gaseous.

In spite of the diversity of research topics determined by this committee to be crucial to present and future pulse power technology development, a recurrent theme surfaced: Technology development must be preceded by a

commitment to basic research. Pulse power technology development has traditionally lacked this commitment, due in part to the "hardware" orientation pulse power and due in part to the lack of basic research tools. This latter cause has been somewhat tempered during the last few years as a result of advances in both experimental diagnostics and theoretical modeling. Further tempering or elimination of this impediment can be accomplished by devoted more funds to these topics. In the discussion for every topic, the need for basic, long term measurements and modeling was stressed time and time again. The following recommendations are made by this committee to foster the atmosphere for basic research in pulse power:

1. Funding agencies should allocate some fraction of their resources to long term (2-3 years) basic research. This commitment would enable the continuity required for basic research and allow sufficient time for basic research to "iterate" with concurrent technology development programs.
2. Basic science sessions should be initiated at the Pulse Power Meeting and Power Modulator Symposium in order to encourage persons working on basic research related to pulse power to attend these meetings. In this way, the overlap of awareness between basic research and technology development projects can be increased.
3. Interaction between the attendees of the traditional pulse power meetings and related conferences such as the Gaseous Electronics Conference should be formally fostered. Many of the basic cross section measurements and modeling required for pulse power applications are discussed at such conferences.
4. Since there does not exist a "pulse power journal", publications in the field are found interspersed in a variety of journals. Also, many publications of interest to the pulse power community appear in conference

proceedings (other than the Pulse Power Meeting and Power Modulator Symposium) or contractor reports. Therefore, keeping abreast of the current status in pulse power research is difficult. This committee recommends the establishment of a bi-monthly pulse power newsletter which would publish current citations (author, title, abstract) of all pertinent works. This newsletter should solicit subscription in the attempt to be self-supporting, however start-up funds from federal agencies may be required.

5. One of the most scarce resources in the pulse power community are qualified engineers and

scientists familiar with the pertinent issues and technology. This scarcity results in part from the trickle of students receiving advanced degrees each year in the field. This situation cannot go uncorrected for long without detrimentally affecting the present and immediately foreseen technology development programs. This committee recommends the establishment of a program of fellowships devoted to graduate study in pulse power. These fellowships should be awarded to deserving outstanding students (as opposed to institutions) to both foster and encourage their research and subsequent entry into the field.

## RESEARCH TOPIC

**DIELECTRIC AND PLASMA-DIELECTRIC INTERFACES**

## 1. Brief description of research topic.

Voltage scaling in energy storage and transmission devices, switches, laser cavities, etc. are presently limited by flashover along dielectric interfaces (solid-vacuum, gas, liquid). Work has to be done to analyze failure mechanisms and to improve interface reliability.

## 2. What are the key research issues?

The key research issues are to gain a basic understanding of charge carrier multiplication along dielectric interfaces and to create a data base for material combinations common in pulsed power devices.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Cross sections for electron emission.
- b) Charge multiplication coefficients along interfaces.
- c) Data on charge accumulation on interfaces.
- d) Gas adsorption and desorption data.
- e) Data on aging of dielectrics and dielectric surfaces under harsh conditions (surface damage, radiation (UV, X-ray), plasmas).
- f) Models and model calculations for breakdown along dielectric interfaces.

All data are needed for different materials and material combinations promising for applications in pulsed power and depending on geometry related boundary conditions.

## 4. How does this research support this application?

These data (s.3, above) will allow engineers to define surface conditions and to predict operating conditions that cause surface flashover. With this information design criteria for pulsed power devices can be developed, and their regime of operation will be extended to higher voltages.

**RESEARCH TOPIC****HIGH CURRENT DISCHARGES****1. Brief description of research topic.**

Pinching of high current discharges such as in thyratrons limits the operation of these devices in the high current regime. A better understanding of the transition into the pinch mode will allow extension of the regime of the operating of switches, to higher currents and longer pulses.

**2. What are the key research issues?**

The key research issues are to understand the behavior of high current gas discharges in complex geometries and its transition into the pinch mode and to investigate the influence of effects such as gas pumping and different types of instabilities on this transition.

The research should be performed as an iterative process of experiments and discharge modeling. Discharge models for the steady state phase as well as for the transient behavior of the discharge are needed.

**3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?**

For the general understanding of high current discharges and for the modeling of these discharges basic data on switch gases and gas mixtures are needed such as cross sections and rate constants at room temperature and elevated temperatures. Discharge experiments should be performed to investigate the influence of plasma-wall interaction on the plasma distribution and on the development of instabilities.

**4. How does this research support this application?**

A better understanding of the discharge in the high current mode will allow a better optimization of switch geometry, fill gas and operation conditions for the hold-off phase and the conduction phase, for both short and long-pulse operation.

## RESEARCH TOPIC

### COLD CATHODES

#### 1. Brief description of research topic.

The major research objective is to develop cold cathodes (immediate turn on in stand-by situation) for switches, gas discharge lasers, etc. with low forward voltage drop, high current densities, stable homogeneous operation, and long lifetime.

#### 2. What are the key research issues?

The key research issues are to understand and describe the emission mechanisms in the turn on mode and the steady state mode. Information needed for both operation modes includes: the emission mechanisms, current distribution, and the cathode plasma interaction for specific switch gases. Lifetime considerations are linked to the migration of low work function materials in the cathode matrix.

#### 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Data on all kinds of secondary emission coefficients.
- b) Characterization of cathode surface structures and its shot-to-shot changes.
- c) The resulting surface field distribution.
- d) Changes of the cathode material composition at the surface caused by sputtering, hot spots, and the migration of the emitter material from inside the matrix.

#### 4. How does this research support this application?

These data will allow the optimization of cathode designs (materials, conditioning, geometry, etc.) for high current switches, lasers and other plasma sources.

#### 5. What research is needed that is not funded?

No basic cathode research is currently funded for heaterless high current cathodes.

## RESEARCH TOPIC

## HIGH TEMPERATURE DIELECTRICS

## 1. Brief description of research topic.

The development of solid and gaseous dielectrics for various applications at elevated temperatures, with high dielectric strength and long term stability.

## 2. What are the key research issues?

Solid dielectrics: Development of dielectrics which can be applied to amorphous magnetic materials (e.g. Metglass) and survive annealing cycle temperatures.

Gaseous dielectrics: Development of gases and gas mixtures with high dielectric strength for switches (spark gaps, etc.) which survive the high current discharge or recovery.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Solids: Existing materials have to be tested with respect to temperature dependent material properties and totally new materials have to be developed.

Gases: Basic data on rate constants at elevated temperatures of gases and gas mixtures (regenerative plasma chemistry) are needed.

## 4. How does this research support this application?

Such new materials will extend the operation regime of pulsed power devices into the high temperature regime as needed for high repetition rates and reduce cooling requirements.

## RESEARCH TOPIC

## DIFFUSE DISCHARGE OPENING SWITCHES

## 1. Brief description of research topic.

Development of diffuse discharge opening switches (electron beam and/or optically controlled diffuse discharges) with low forward resistance, fast opening times, and high hold-off capability.

## 2. What are the key research issues?

Investigation and optimization of basic processes for external discharge control such as electron generation processes (e-beam and UV ionization) and control of electron depletion processes (E/N dependence of attachment, photo-enhanced attachment (IR, UV), photodetachment), gas discharge experiments with specific switch gases, discharge modeling, and prototype switch development.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Basic data on control processes such as attachment and photodetachment, especially from excited states and at elevated temperatures.

## 4. How does this research support this application?

Inductive energy storage using opening switches will significantly reduce storage weight and volume requirements and allow operation with low prime power voltages.

## 5. What research is needed that is not funded?

Development of a switch prototype.

## RESEARCH TOPIC

## DIAGNOSTICS

## 1. Brief description of research topic.

Investigate and develop predictive methods to determine the "state-of-health" of a pulsed power sub-system without test runs.

## 2. What are the key research issues?

- a) Investigation of failure mechanisms.
- b) Development of reliability predictors.
- c) Development of passive measurements of system conditions.
- d) Development of transducers for transient measurements (voltage, current) in absence of reference.
- e) Development of calibration standards.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Same as No. 3.

## 4. How does this research support this application?

The proposed research will provide a systematic approach to provide methods and tools to determine the "state-of-health" of pulsed power systems.

## 5. What research is needed that is not funded?

No work is funded in this field.

**RESEARCH TOPIC**  
**DC TO DC CONVERSION**

1. Brief description of research topic.

Investigate high-frequency techniques for lightweight, high-power DC-to-DC converters which are required in high-power-laser power conditioning stages following the prime-power stage.

2. What are the key research issues?

- a) Identify optimum input/output voltage.
- b) Determine inverter switch/rectifier trade-offs.
- c) Identify optimum switching (resonant) frequency.
- d) Transformer design: magnetic materials, winding configuration.
- e) Feedback/Control/Regulation Topology.
- f) Compact, lightweight packaging.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Same as in No. 3.

4. How does this research support this application?

This research will develop the components/techniques which are required for 300 V DC to 100 kV DC converters which are required for high-power lasers.

5. What research is needed that is not funded?

All items under 2.

**Section II**

**Report of the**

**MICROWAVES and EMP/SIMULATION**

**COMMITTEES**

**P.F. Williams, chairman**

# MICROWAVES and EMP/SIMULATION

## Committee Members:

P.F. Williams, C.R. Jones (chairmen),  
G. Frazier, M. Heyne, E.E. Kunhardt,  
A. Ramrus, K. Schoenbach, J. Stover

## SUMMARY

### Microwaves

The committee selected three general research areas in which broadly based programs are needed. In approximate order of importance, these areas are: 1) Failure of insulators, particularly failure at interfaces; 2) High voltage, bulk solid state switches; and 3) Electrical, microwave, and optical breakdown mechanisms of gases as relevant to switches. The committee recommended that university or joint university/industry based research emphasize programs likely to produce basic understanding or knowledge applicable to a family or families of devices, rather than development programs aimed at only one, specific, application. These programs should be of evident importance, but of sufficient generality and risk as to be given low priority in industrial research laboratories.

#### 1. Failure of Insulators

Unintended failure of insulators is a constant problem in high voltage systems. Although a sufficient technological base probably exists for designing conventional systems with acceptably low risk of such failure, very little is known about the cause of flashover in an undervolted system. This area was given high priority by the committee primarily for two reasons. First, good engineering practice today involves designing in substantial safety factors in order to reduce the occurrence of flashover. Understanding of the important factors involved should allow less conservative design rules, thereby reducing cost and weight in these systems. Second, experience with engineering high voltage systems for use in

space is minimal, and the applicability of ground-based engineering design rules to the space environment is unknown. Detailed, quantitative information about failure mechanisms is needed, therefore, to assess the reliability of space based systems.

In all media the development of a numerical modeling capability will play an important role and will provide the basis for the development of computer aids for system design. In gases and in vacuum the general mechanisms of overvolted breakdown are qualitatively understood, but much more research is needed into the reasons for undervolted breakdown. In solids some information about breakdown (primarily in the depletion region of semiconductors) is available, but much more work is needed, particularly for insulating solids. In liquids there is essentially no understanding of breakdown at all. Probably of most concern is the question of flashover at interfaces. The possibility of surface flashover at dielectric interfaces requires very conservative design practices in high voltage systems, and surface flashover of semiconductors is a limiting problem in high voltage solid state devices. Field crowding is a factor in this flashover, but other, poorly understood, mechanisms also are important and should be studied.

#### 2. High Voltage, Bulk Solid State Switches

The potential advantages of solid state devices over spark gaps and diffuse discharge switches are evident, particularly for space applications. In most existing devices the off-state voltage appears across a narrow depletion region, and the hold-off voltage is therefore limited to several kV. In bulk devices such as photoconductive, electron beam controlled, and (DI)<sup>2</sup> (Deep Impurity, Double Injection) switches, the voltage is dropped across a much longer region of the bulk material and much higher hold-off voltages should be possible. The suitability of these devices for pulsed power applications is by no means demonstrated, but because of the

## MICROWAVES and EMP/SIMULATION COMMITTEES

enormous potential advantages of the solid state approach substantially more research is warranted. Specific areas of interest include modeling, bulk and surface breakdown mechanisms, trapping and associated space charge effects on carrier transport, carrier injection at contacts, current filamentation, and device fabrication and testing.

### 3. Electrical, Microwave, and Optical Breakdown of Gases

Quantitative understanding of the breakdown of gases is needed to minimize switch delay and jitter, and to maximize current density and  $dI/dt$  in switches of all types. The tools needed for substantial advances, particularly in modeling, now exist and should be applied. The electrical breakdown of gases is of obvious importance to spark gap, and thyatron and other diffuse discharge switch technology. The general mechanisms of breakdown are fairly well in hand, but work is needed on quantitative understanding of transient effects such as the initial breakdown process, the glow-to-arc transition, and the triggering of breakdown. Optical breakdown is a primary component of some advanced triggering schemes. Information is needed regarding the source of the initial electrons, as well as more quantitative predictive ability about the breakdown process. Finally, discharges can be used as high power microwave switches. Such devices are commonly used as T.R. switches in radar systems. The use of discharges driven by microwaves in combination with electrical or optical excitation has been suggested for switching high power microwave pulses out of a resonator cavity. The transient kinetics of the microwave-plasma interaction, as well as the development of quantitative understanding of the plasma driven by the mixed power sources are needed.

### EMP/Simulation

The committee identified three major simulation applications in which the state of switching technology limits further advances. These applications are hard EMP, source range EMP,

and X-ray simulation. For hard EMP applications, the primary need is for lower inductance, multimegavolt closing switches; for source range EMP high coulomb closing switches are needed; and for X-ray simulation vacuum opening switches are needed. In all areas improved capacitive energy storage is also needed. The state-of-the-art devices in current use for these applications are all relatively well optimized, and further advances of the magnitude needed will require revolutionary new approaches.

Detailed suggestions for basic research are spelled out in the following section. Briefly, improvements in low inductance, high voltage switches will require improved quantitative understanding of and predictive ability for triggered breakdown of gases. The inductance of a switch can be reduced by increasing the dielectric strength of the fill gas so that a shorter gap length can be used for a given hold off voltage, or by inducing the formation of multiple arc channels. A fast risetime switch also requires a rapid and reliable glow-to-arc transition. By tailoring gas mixtures and by other innovative techniques, it is probably possible to improve substantially on devices currently available. Doing so will require significant advances in the quantitative understanding of gas breakdown under conditions appropriate to such switches, and in our numerical modeling capability.

Electrode erosion is the primary problem with high coulomb closing switches. Quantitative understanding of the arc in such switches will likely lead to switch designs featuring lower arc voltages (and therefore lower energy deposited in the gap) than are currently available. Substantial improvements in such switches will probably require new and innovative ideas for switch design, however. For example, one idea is to use an external, transverse magnetic field to push the arc around on the electrode, thereby spreading out the region of erosion. Very little is known, however, about the dynamics of the arc-magnetic field interaction. Knowledge of the dependence of the velocity of arc motion on external parameters, as well as arc sticking

## MICROWAVES and EMP/SIMULATION COMMITTEES

will be required before such a high coulomb switch can be designed.

Vacuum opening switches are needed to achieve 100 TW power levels for X-ray simulation. The primary concern here is the control of unwanted plasma conduction during the turn off phase of

operation. Quantitative understanding of the opening phase of a vacuum gap, coupled with new, innovative ideas for reducing current conduction during this phase are needed. Other questions include the effects of the load on switch operation, and the effects of radiation-induced damage to the switch.

## RESEARCH TOPIC

## LENSES FOR ELECTROMAGNETIC WAVE LAUNCHING

1. Brief description of research topic.

Electromagnetic lenses are needed to transport electromagnetic energy from the pulser to the test volume in EMP simulators with low loss. The technology for doing so is not yet developed.

2. What are the key research issues?

- a) Design
- b) Graded structures
- c) Material selection

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

The capability of transporting megavolt pulses at less than 100  $\Omega$  uniform transmission line impedance levels through multiple interfaces with spatially varying dielectrics is needed. The basic physical understanding required for designing such systems exists, but it must be applied and insight must be developed.

4. How does this research support this application?

The research is required in order to be able to design such systems.

## RESEARCH TOPIC

## CAPACITIVE ENERGY STORAGE

1. Brief description of research topic.

Most capacitive energy storage systems in present use are capacitive. Especially for air and space borne applications, higher energy storage density with low inductance are needed. This research addresses improvements in technology directed towards this goal.

2. What are the key research issues?

The primary issue here is understanding the fundamental properties of dielectrics. Specific issues include breakdown strength, dielectric constant, response time, effects limiting lifetime, and the effect of impregnants.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

The dielectric response of relatively simple, crystalline solids is well understood at a basic physics level. Even for these material, however, factors affecting dielectric strength and breakdown are not well known. More information about the more complex, often amorphous, materials used in high energy density capacitors is needed.

4. How does this research support this application?

Capacitors with increased energy storage density with decreased inductance are needed for many pulsed power applications. Substantial progress in this direction has been made recently, and further advances are probably possible.

5. What research is needed that is not funded?

Substantial research in this area is already being carried out, primarily in industrial laboratories. Although further research is very likely to yield impressive improvements in this area, the likely impact of increased university-based research activity in this area is not clear.

## RESEARCH TOPIC

## GASEOUS OPENING SWITCHES

## 1. Brief description of research topic.

Opening switches are needed for inductive energy storage. Inductive storage has the potential of being lighter and cheaper than capacitive storage, but suitable opening switches don't exist presently.

## 2. What are the key research issues?

- a) E-beam sustained devices
- b) Physics of opening process
- c) Use of tailored electro-negative gases
- d) Modeling
- e) Fundamental transport parameters

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

The primary need is for reliable, quantitative modeling capability in these systems. Particularly for exotic gas additives, information about fundamental transport properties is needed.

## 4. How does this research support this application?

Opening switches are required to make use of inductive energy storage. Gas discharge devices are the most advanced presently, but are far from being suitable for most applications. This research will provide the knowledge base necessary to optimize existing design ideas, and to generate new ideas.

RESEARCH TOPIC  
VACUUM OPENING SWITCHES

1. Brief description of research topic.

Vacuum inductive storage is required to achieve economically 100 TW power levels in radiation effect simulation. Vacuum opening switches are the key elements in achieving this goal. This research seeks to understand the fundamental issues affecting the performance of these switches.

2. What are the key research issues?

- a) Restrike
- b) Control of unwanted plasma conduction
- c) Radiation induced damage to switch elements
- d) Switch-load coupling

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Switches are needed which are capable of conducting megamps over microsecond periods and then opening with megavolt applied voltage.

4. How does this research support this application?

This is an enabling technology for these simulation systems.

## RESEARCH TOPIC

## HIGH COULOMB CLOSING SWITCHES

## 1. Brief description of research topic.

Gas discharge closing switches used in source range EMP ground burst simulation (Direct current injection) require improvements to attain threat levels. This research addresses closing switches operating in the range of 10's of KV and 10-100 Coulombs of charge transfer. Switches of this capability are required to reach threat level.

## 2. What are the key research issues?

- a) Arc-discharge-induced mechanical effects
- b) Materials (electrode and envelope erosion)
- c) Erosion control
  - i) Magnetic arc deflection
  - ii) Material and geometry selection

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Present switches are capable of transferring 5-10 Coulomb; about 10-100 Coulomb is needed. Modeling capability for these high current arcs is needed, as is understanding of the effects causing anchoring the arc spot.

## 4. How does this research support this application?

The results of the research will provide the knowledge and understanding required for new switch designs needed to achieve threat levels in source range EMP simulation.

## RESEARCH TOPIC

## LOW INDUCTANCE, MULTIMEGAVOLT CLOSING SWITCHES

## 1. Brief description of research topic.

In advanced EMP systems the output risetime is a critical parameter which depends upon the design of the output switch and limits the performance of these systems. This research addresses fundamental issues limiting the performance of these switches and will provide the knowledge base needed for revolutionary new switch design ideas.

## 2. What are the key research issues?

- a) Breakdown strength and tailoring of fill gas mixtures.
- b) Attainment of low inductance through multichanneling with
  - i) Mid-plane triggering
  - ii) Laser triggering
  - iii) Uniform discharges
  - iv) Preionization
  - v) Photoconductive switches

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Switches exhibit an inductance of about 50 nH/MV presently, and about 5 nH/MV is needed. For tailoring of gas mixtures and understanding of multichanneling substantial improvements in modeling capability will be required. Particularly for the more exotic gas additives, there will also be a need for more information about fundamental transport parameters.

## 4. How does this research support this application?

Switch risetime limitations are a fundamental bottleneck to advanced EMP applications. This research will provide the knowledge base necessary for improving the risetime of these switches.

## RESEARCH TOPIC

## MICROWAVE-PLASMA INTERACTION

## 1. Brief description of research topic.

Plasmas are used in transmit-receive (T.R.) switches and have been suggested for high power microwave conditioning. A key element in these applications is the interaction between the plasma and the microwave radiation. This interaction is also important for applications involving the propagation of medium and high power microwave radiation in the tenuous plasma of the near-Earth space environment.

## 2. What are the key research issues?

- a) Microwave breakdown
- b) Interaction of electrical or optical fields with microwave fields
- c) Breakdown times and jitter
- d) Modeling
- e) Tailoring of gas mixtures for switches, and the chemical stability of these mixtures in high repetition rate devices

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

A quantitative predictive modeling capability is needed. This goal will require the acquisition of basic transport parameters for the gases under consideration, and may require the extension of existing theories of microwave-induced plasma heating.

## 4. How does this research support this application?

The development of a physically based understanding and knowledge base relevant to the microwave-plasma interaction will allow the determination of the fundamental limitations on the performance of these devices and will provide the basis for design improvements.

## RESEARCH TOPIC

## INITIAL BREAKDOWN MECHANISMS IN GASES

## 1. Brief description of research topic.

Arc and diffuse discharge switching devices are commonly used in a wide range of pulsed power applications. The dynamics of the initial breakdown process determine critical switching parameters such as closing delay and jitter. For arc discharge devices, the goal is to induce low resistance arc formation as rapidly and reliably as possible, whereas for diffuse discharge devices arc formation is to be avoided. Quantitative information about the detailed physical mechanisms governing the initial glow formation as well as the possible subsequent glow-to-arc transitions in gas mixtures relevant to these devices is needed to improve the turn-on characteristics in these switches, as well as to increase the current handling capability of diffuse discharge devices. The development of a reliable modeling capability will be essential.

## 2. What are the key research issues?

- a) Factors affecting closure time and jitter, and current risetime.
- b) Tailoring of gas mixture
- c) The relative role of "streamer" and "Townsend" breakdown in triggered switches
- d) Triggering mechanisms
- e) Modeling
- f) Determination of fundamental transport parameters
- g) Electrode effects, including surface composition and roughness
- h) Glow-to-arc transition
- i) Chemical decomposition of the fill gas in the arc

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Quantitative information about the initial breakdown leading to a predictive capability is needed. The development of numerical modeling techniques, coupled with the acquisition of basic transport coefficient information will be required.

**Initial Breakdown Mechanisms in Gases -- (continued)****4. How does this research support this application?**

The research will provide the knowledge base required to optimize gaseous switches by determining the detailed limiting mechanisms in these devices and will lead to the development of the predictive modeling capability necessary for the design of new switches.

**5. Comments:**

The electrical breakdown of gases is a relatively mature research field. There has been little application of the existing basic physical understanding of breakdown in general to problems specifically relevant to switches, however. Most types of triggered breakdown are understood at only the most qualitative level, and predictive design formulae are presently almost entirely phenomenological. The tools exist for developing a basic physics based understanding of these topics and they should be applied.

## RESEARCH TOPIC

## BULK SOLID STATE SWITCHES

## 1. Brief description of research topic.

This research will seek to understand and to assess the feasibility of high voltage solid state switches in which the voltage is dropped across a relatively long region of high resistivity semiconductor material. The basic physics involved in these devices should be determined and the limitations on and trade-offs associated with attaining peak voltage and current determined.

## 2. What are the key research issues?

- a) Determination of performance limits of
  - i. optically controlled (photoconductive),
  - ii. electron-beam controlled, and
  - iii. (DI)2 (Deep Impurity, Double Injection) devices
- b) Carrier injection at contacts
- c) Efficiency of control (gate energy/energy switched)
- d) On-state losses
- e) Instabilities and current filamentation
- f) Transient behavior
- g) Modeling
- h) Materials and device fabrication techniques

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Surface flashover is a major limitation with these devices, and is very poorly understood. The development of a quantitative modeling capability will be required to develop and assess improved device designs. Trapping and ionization cross sections and other basic transport parameters for silicon and other semiconductors are needed.

## 4. How does this research support this application?

This research directly assesses the feasibility of high voltage solid state switches for use in pulsed power applications, and it addresses the known problems in the design of such switches.

## 5. Comments:

This field has received very little attention or support until very recently. It requires a great deal of basic research, and is high risk, but the potential pay-offs are enormous.

## RESEARCH TOPIC

## FAILURE MECHANISMS OF VACUUM INSULATORS

## 1. Brief description of research topic.

The research will seek quantitative understanding of vacuum flashover, both in the vacuum itself and at vacuum-insulator interfaces. This knowledge will be needed to develop new ideas for reducing the incidence of vacuum flashover, to assess the reliability of vacuum insulated systems in non-conventional environments such as space, and to develop computer codes to aid in the design of these systems.

## 2. What are the key research issues?

- a) Electrode phenomena
- b) Recovery
- c) Vacuum insulator interfaces
- d) Modeling

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Quantitative information regarding the effects of electrode protrusions and surface layers, and the generation and support of a vacuum arc at the cathode are needed. The development of a quantitative predictive modeling ability, especially for recovery is desirable.

## 4. How does this research support this application?

The work will lead to increased reliability and decreased size and weight for high voltage, vacuum insulated systems and for many microwave generation devices.

## 5. Comments:

The application of a magnetic field could improve the hold-off voltage.

## RESEARCH TOPIC

## FAILURE MECHANISMS OF LIQUIDS AND AMORPHOUS MEDIA

## 1. Brief description of research topic.

The research seeks understanding of the electrical breakdown of liquids and of amorphous media such as many plastics. Liquids such as water are used as the dielectric in transmission lines, and most high voltage systems are immersed in oil or other liquid insulator. Many solid insulators are amorphous plastics. Presently there is not even the most qualitative knowledge of the basic physical mechanisms of breakdown in these materials. Clearly such information is needed to design and assess the reliability of high voltage systems using these insulating media, particularly for operation in unfamiliar environments such as space. The development of quantitative modeling techniques should also be encouraged as part of the program.

## 2. What are the key research issues?

- a) General understanding of breakdown
- b) Fundamental transport properties and parameters
- c) Solvation at interfaces
- d) Failure at interfaces
- e) Electrode effects
- f) Effects of impurities
- g) Modeling
- h) Long term chemistry effects

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

The primary need is the determination of the breakdown mechanisms. Also fundamental parameters such as cross sections or transport parameters are badly needed.

## 4. How does this research support this application?

This information is needed to design smaller and lighter high voltage systems, and to assess and improve reliability of these systems.

## RESEARCH TOPIC

## FAILURE MECHANISMS OF CRYSTALLINE SOLIDS

## 1. Brief description of research topic.

The research will seek quantitative understanding of electrical breakdown in crystalline solids, primarily semiconductors. Breakdown in the bulk is of interest, but the primary concern should be surface breakdown. This knowledge will be needed to assess ideas for and design new high voltage (10-100 kV) solid state switches, as well as to improve the reliability of crystalline solid insulators.

## 2. What are the key research issues?

- a) Surface breakdown
- b) Carrier injection and other electrode effects
- c) Role of impurities including trapping and recombination centers
- d) Modeling

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Information on the mechanisms of surface flashover in semiconductors is needed, as is the development of a quantitative modeling capability. Quantitative information on transport properties such as ionization coefficients, collision cross sections, etc. will be required for the modeling.

## 4. How does this research support this application?

This information is needed for design of high voltage solid state switches, for reliability assessment of solid electrical insulators such as sapphire or BeO, for minimizing insulator thickness for thermal and weight management, and for electric field shaping.

## RESEARCH TOPIC

## FAILURE MECHANISMS OF GASEOUS INSULATORS

## 1. Brief description of research topic.

This research program will seek quantitative understanding of the unintentional breakdown of gaseous insulators in high voltage systems. Presumably such breakdown is the result of some unexpected perturbation. The research should identify the perturbations most commonly at fault and understand and determine the magnitude of perturbation required. This study will necessarily be quantitative and modeling will play an important role. Flashover at dielectric interfaces, such as at solid insulator surfaces, should also be studied.

## 2. What are the key research issues?

- a) Failure at interfaces including material and geometry effects.
- b) Modeling
- c) Tailoring of gas mixtures to improve reliability
- d) Effects of impurities in the insulating fill gas

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

A quantitative predictive ability for determining streamer properties in undervolted gaps and for the glow-to-arc transition in glow discharges is needed. Particularly for the more exotic fill gases a number of cross section and/or transport parameters will be required.

## 4. How does this research support this application?

Proper understanding should lead to less conservative design rules, which will allow smaller, lighter high voltage systems. Understanding is also necessary for assessing insulator reliability in unfamiliar environments such as space, and for intelligent choice of fill gas mixtures for minimizing the probability of flashover.

**Section III**

**Report of the**

**EM LAUNCHERS COMMITTEE**

**Robert DeWitt, chairman**

# EM LAUNCHERS

## Committee Members:

R. DeWitt (chairman), R. Askew, R. Dougal, L. Hatfield, J. Hyman, F. Rose, C. Thio

## SUMMARY

Since the principal of electromagnetic launchers is derived either from the Lorentz force resulting from the interaction of a current with a magnetic field or the Amperian force resulting between currents, research can be found over a period as long as the existence of Maxwell's equations on using this force for acceleration. However, the physics and engineering issues associated with meaningful power sources did not receive a vigorous and sustained study until the late 1970's when homopolar generators were used for power sources. Since then far more attention has been devoted to the rail accelerator than other EM launchers or other power components. Recent attention through SDI on kinetic energy weapons has intensified the work on rail accelerators and pointed out the need for more research on space-based high-power conditioning.

Key research issues associated with the rail accelerator are:

1. Ablation: Rail and coating materials are ablated from the bore walls in the high current discharge. This material contaminates the driver arc and is subsequently accelerated with the projectile resulting in an energy loss.
2. Plasma drag, break-up, and blow-by: The high pressure in the driver arc leads to an extremely high shear boundary layer resulting in a plasma drag which reduces propulsion. Instability and turbulence in the driver arc gives rise to armature break-up, while arc plasma leaking around the projectile reduces its acceleration.
3. Arc restrike: Restriking arcs behind the projectile lead to current division and loss of acceleration.
4. Materials: Tremendous Joule heating and magnetic forces lead to rail failure and energy losses, while material and plasma interactions give rise to complex boundary conditions.
5. Diagnostics: Sophisticated mechanical and plasma processes develop rapidly in time and space requiring state-of-the-art diagnostics to be extended for space and time resolution. These processes are described by a very large number of parameters implying that extensive diagnostics is necessary to develop a clear, quantitative understanding. Added to this is the fact that the accelerator operating-environment is a harsh EM environment making in situ measurements difficult.

While these are some of the key issues in rail gun technology, it is apparent that not all of them go over into key research issues associated with power conditioning for EM launchers. In this respect, it was determined that materials and diagnostics were not appropriate key issues for the workshop. However, systems/environment considerations brought forth the following additional key issues:

1. Plasma arc (driver) characterization: This arc is the major load in the power conditioning circuit representing a variable resistance and inductance. Detailed characterization of this arc thus heavily impacts the power conditioning system. Closely associated with the driver arc characterization is the detailed computer modeling of the rail accelerator. It is felt that a substantial effort should be supported in the analytical and numerical study of the plasma, electrodynamic, and mechanical processes associated with the operation of the accelerator. Studies based on

## EM LAUNCHERS COMMITTEE

incomplete models or gross simplifications are not sufficient to answer important questions dealing with the success or limits of rail accelerators.

2. Plasma arc (switching): Since most switching will involve arcs and are the current carrying medium, switch parameters such as V-I characteristics, recovery, efficiency, etc. will be very important in the power conditioning for rail guns.
3. Novel energy conditioning schemes: Since brute force power conditioning leads to technology barriers associated with voltages > 10 kV, currents > 1 MA and powers > 1 GW, it is necessary to investigate alternate schemes to either by-pass the barriers or reduce the effects of severe requirements on components.
4. New dielectric materials: Because mission requirements demand efficient, reliable high-power transmission, it is necessary to develop new materials with high dielectric constants ( $>1000$ ), low losses (loss tangent  $< 0.0005$ ), high dielectric strengths ( $>1000$  MV/m), and high flashover thresholds ( $>200$  kV/cm).
5. Electrochemical storage and conditioning: Since volume and weight of energy storage is crucial in the deployment of space-borne systems, it is necessary to develop storage systems that have battery-like storage densities, but capacitor-like discharge characteristics. These materials must operate with high current densities ( $>50$  kA/cm<sup>2</sup>), high energy densities ( $>50$  kJ/kg), and high power densities ( $>250$  kW/kg).
6. Electromechanical components: If homopolar generators are used with rail guns, key issues will be high current collection ( $>100$  kA/cm<sup>2</sup>), low brush losses and debris management associated with zero gravity operation.

## RESEARCH TOPIC

## PLASMA ARC DRIVER (LOAD)

## 1. Brief description of research topic.

Arc discharge is the driver representing variable R and L which impacts power conditioning.

## 2. What are the key research issues?

- a) Losses - radiation, re-strike (current distribution), others
- b) Modeling - full range of processes, verification
- c) Viscous drag
- d) Erosion
- e) Upper limits on power technology requirements
- f) Supporting diagnostics

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Spatial and temporal data on:

- a) Plasma temperature and particle density
- b) Hydrodynamic pressure
- c) Arc current distribution
- d) Gross characteristics of viscous drag
- e) Erosion species
  - i) identification
  - ii) rate (amounts)
- f) Effects on plasma arc

## 4. How does this research support this application?

Power conditioning requirements cannot be determined without this knowledge

## 5. What research is needed that is not funded?

All/Any

RESEARCH TOPIC  
PLASMA ARC (SWITCHING)

1. Brief description of research topic.

Plasma arc as the current carrying medium in switching in EM Launchers is an element of power conditioning of the system.

2. What are the key research issues?

Switch characteristics.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Jitter
- b) V-I characteristics
- c) Life-testing
- d) Recovery (rep-rate)
- e) Efficiency

4. How does this research support this application?

Power conditioning requirements cannot be determined without knowledge of switch characteristics.

5. What research is needed that is not funded?

- a) State-of-the-art diagnostics should be applied to specific hardware.
- b) University funding for generic experimental and theoretical research.

RESEARCH TOPIC  
NOVEL ENERGY CONDITIONING SCHEMES

1. Brief description of research topic.

Alternate conditioning to sidestep barriers at voltages  $> 10$  kV, currents  $> 1$  MA and power  $> 1$  GW.

2. What are the key research issues?

- a) Electrical breakdown limits.
- b) Alternate approaches that eliminate or reduce electrical requirements of components
- c) Increased efficiencies.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Same as #2 above.

4. How does this research support this application?

As alternate approaches to overcome severe technology requirements of the conventional approach.

5. What research is needed that is not funded?

- a) Arc-free interruption of circuit at 50 kA, 200 kV and greater.
- b) Pulse transforming schemes at high power.

6. Comments:

The rail-gun-switch problem must be solved within a limited timeframe whether the present approaches are optimum or correct. This research will attempt to establish the feasibility of an alternate approach with a small portion of the funding applied to the conventional approach of Homopolar Generator and 2 MA switch.

## RESEARCH TOPIC

## ELECTROCHEMICAL STORAGE AND CONDITIONING

## 1. Brief description of research topic.

Electrochemical systems with battery-like storage densities but capacitor-like discharge characteristics.

## 2. What are the key research issues?

- a) Current density
- b) High-rate ion transport (modify)
- c) Field effects
- d) Large surface area materials
- e) Energy/power density
- f) Losses/thermal management
- g) Chemical double layer

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Current density  $> 50 \text{ kA/cm}^2$
- b) Surface area  $> 200 \text{ m}^2/\text{gr}$
- c) Magnetic field, electric field, mobilities, - what are the limits.
- d) Power  $> 250 \text{ kW/kg}$

## 4. How does this research support this application?

Provides lighter weight systems and avoids problems of rotating machinery.

## 5. What research is needed that is not funded?

All/Any

**RESEARCH TOPIC**  
**NEW DIELECTRIC MATERIALS**

1. Brief description of research topic.

New insulation and storage dielectric materials.

2. What are the key research issues?

- a) Dielectric constants
- b) Loss tangent
- c) Voltage breakdown
- d) Tracking/flashdown phenomena
- e) Large scale manufacturability
- f) Vapor pressure

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Dielectric constants > 1000
- b) Loss tangent < 0.0005
- c) Voltage > 1000 MV/m
- d) Flashover > 200 kV/cm

4. How does this research support this application?

Provides lighter weight systems and reduction in thermal management.

5. What research is needed that is not funded?

Work on materials other than polymers.

## RESEARCH TOPIC

## ELECTROMECHANICAL COMPONENTS

## 1. Brief description of research topic.

Power conditioning problems associated with homopolar generators.

## 2. What are the key research issues?

- a) Current collection
- b) Debris management
- c) Pick-up lifetime
- d) High voltage capability

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Current density  $> 100 \text{ kA/cm}^2$  or  $I > 1 \text{ MA}$
- b) Characterization and solution of brush losses
- c) Lifetime  $>$  burst-mode
- d) Output voltage  $> 2 \text{ kV}$

## 4. How does this research support this application?

Performance requirements of EMLs only achievable from homopolar generators with improvements to above levels.

## 5. What research is needed that is not funded?

Debris characterization from contact wear.

**GENERAL ISSUES - SUMMARY OF COMMITTEE COMMENTS**

1. List the most important problems requiring research, in order of importance, if possible.
  - a) Plasma arc driver (load) - theoretical and experimental characterization.
  - b) Electrochemical storage and conditioning
  - c) New dielectric materials.
2. What should be done to get scientists and engineers to talk or interact with each other?
  - a) Lower costs associated with attending meetings.
  - b) Sub-topics within pulse power should identify common journals for publication.
3. Suggestions for Industry-Government-University interactions.
  - a) More IEEE and AIAA sponsored symposia at universities to reduce costs.
  - b) More commonly identified journals for publication.
  - c) Industry should host more symposia.
4. What kinds of or changes in meetings should be occurring? What are the most valuable? Should there be technical subgroups within the pulsed power or other meetings for any or all of the research areas? If so, how should they be organized?

Pulse power conference should consider meeting yearly, with enough poster secession to cover the broad range of current research.
5. How should research be communicated to users? Refereed publications, unrefereed publications, conferences, technical reports, panel review, or through monitors? Which meetings or conferences? Which are the most appropriate refereed journals, in order of priority?

Refereed publications should remain preferred.

Primary: J. Appl. Physics  
IEEE Transactions

**Section IV**

**Report of the**

**MAGNETIC FUSION COMMITTEE**

**J.A. Kunc, chairman**

# MAGNETIC FUSION

## Committee Members:

J.A. Kunc (chairman), W. Byszewski,  
D. Huttar, H. Kuehl, J. Laghari, P. Rock

## SUMMARY

The committee reviewed both current issues of fusion research related to power conditioning and those issues that seem to be essential for futural growth of the field. We concluded that the most important problems in power conditioning for magnetic fusion, in order of importance, are:

Fault Protection (research related to high-energy deposition and the prevention of catastrophic failure producing consequential damage): The key research issues: management of power systems, development of incipient fault detection, replacement for mechanical switching used presently, and passive voltage energy absorbing devices.

Insulating Materials (investigation of insulator materials properties): The key research issues: dielectrics for superconducting coils under high neutron flux fluence, high-current and high-voltage, low-inductance transmission lines for capacitors and development of superior conformal insulators for electrical conductors.

Switching (research related to high-current and high-voltage switching for both closing and opening applications): The key research issues: modeling and diagnostics of plasma processes in the switches, high-current elected technology, energy capacity of the device, recovery time and voltage hold-off.

Prime Power (research on and development of valuable scenarios for powering long-burn fusion reactors at gigawatt level): The key research issues: local energy storage technology for

energies considerably above 10 gigajoules and grid utility.

Power Conversion Systems (research on power system interaction, magnetic components, rectifiers and regulations associated with the next generation fusion devices): The key research issues: mechanical integrity of high-current power transformers and research on relative merits on the applications of forced commutation or GTO devices in conversion systems.

Power Semiconductors (research on semiconductors for power systems): The key research issues: bulk physics of power semiconductors, edge treatment of the voltage hold-off, improvement of switching time and control turn-on and -off capability, better packaging for heat transfer and research on phase transition materials for semiconductors.

## CONCLUSION

The committee concluded that the above research topics are the most needed, from a power conditioning point of view, for advancing the program of development of the next generation fusion experiment. This research will also help to make the magnetic fusion devices cheaper, more compact and more reliable. It is a common feeling among committee members that, in general, the information on which research areas and to what extent, are being funded now or are going to be funded in the nearest future are not easily available for the research community. Therefore this is, practically, quite difficult to recommend what research is needed that is not funded. However, it seems that the most of the power conditioning topics mentioned above are underfunded.

The committee agreed that interaction between researchers of industrial, governmental and academic institutions should be improved. It seems that, in order of importance, workshops,

symposia and conferences are the most valuable forms for such interaction; substantial increase in participation of the industrial sector in these meetings is highly recommended. Also, the meetings should have technical subgroups concentration on particular research areas. In addition, the committee suggests the following forms of industry-government-university interaction in power conditioning research and development:

- a) National and international multi-lab research programs.
- b) Founded projects with specific goals involving both technology developers and users.
- c) Formation of a Technical Government Sub-committee to support and promote research in the area of power conditioning technology in fusion programs.

The committee concluded also that the research-user communication should be improved. It seems that the following steps would be proper to achieve a substantial improvement:

- a) Publishing the proceedings of workshops and symposia.
- b) Formation of a High Power Conditioning Research and Application Organization.
- c) Joint projects involving the technology, research and development and prototypical applications.

The following publications are recommended by the committee for exchange of the information on the power conditioning in fusion research.:

- a) "Proceedings of the Bi-annual Symposium on Engineering Problems in Fusion Research"
- b) "Power Conversion International"

**RESEARCH TOPIC**  
**FAULT PROTECTION**

1. Brief description of research topic.

Phenomena related to high-energy deposition in critical component and the prevention of catastrophic failure producing consequential damage (e.g. capacitor explosion).

2. What are the key research issues?

- a) Management of power systems.
- b) Development of incipient fault detection.
- c) Replacement for mechanical switching used presently.
- d) Passive voltage sensitive energy absorbing devices.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits of boundaries?

We need information on the potential value of alternative technologies in providing reliable systems and component protection in high-power systems (e.g. needed energy absorption capability is of 100 kJ/ whereas the present capability is about 10 kJ/cc).

4. How does this research support this application?

It is one of the most essential topics in advancing the program to the next generation of experimental facilities.

5. What research is needed that is not funded?

Research on competing materials for passive voltage sensitive energy absorbing devices. Research on power system management incorporating an advanced predictive fault detection technology.

## RESEARCH TOPIC

## DIELECTRICS

## 1. Brief description of research topic.

Investigation of insulator materials properties for the next generation fusion reactors.

## 2. What are the key research issues?

- a) Dielectrics for superconducting coils (mechanical and electrical properties under high neutron flux fluence).
- b) High-current and high-voltage low-inductance transmission lines for capacitors.
- c) Development of superior conformal insulators for electrical conductors.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Dielectric constants and strengths and mechanical properties.
- b) We need to know manufacture ability of useful electrical components employing superior insulators.

## 4. How does this research support this application?

- a) Insures the survival of normal and superconducting coils in high-radiation environment of operating fusion reactors.
- b) Reduces size and improves performance of electric supply systems.

## 5. What research is needed that is not funded?

High neutron flux interaction with insulator materials.

## RESEARCH TOPIC

## SWITCHES

## 1. Brief description of research topic.

Research related to high-current and high-voltage DC switching for both closing and opening applications.

## 2. What are the key research issues?

- a) Modeling and diagnostics of plasma processes in the switches.
- b) High-current electrode technology.
- c) Energy capacity of the device.
- d) Recovery time.
- e) Voltage hold-off.
- f) Uniformity of the performance through the bulk of material.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Presently available current about 100 A, voltage hold-off about 30 kV, opening time 7 milliseconds and repetition time 5 min. The desirable goals should be respectively - 300 A, 100 kV, a few microseconds, about the same.

## 4. How does this research support this application?

It will help to make the magnetic fusion devices cheaper, more compact and more reliable.

## 5. What research is needed that is not funded?

- a) Cross sections and oscillator strengths for electron-ion, electron-metastable particle and gas-surface processes.
- b) Application oriented research development and testing related to the items mentioned in Section 3.

**RESEARCH TOPIC****PRIME POWER****1. Brief description of research topic.**

Research and development of viable scenarios for powering long-burn fusion reactors at gigowatt level.

**2. What are the key research issues?**

- a) Grid utility.
- b) Local energy storage technology for energies considerably above ten gigajoules.

**3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?**

We need information on what level of pulse power the utility grid can supply, what limits this power and what the limitations are for the energy storage systems in terms of expectable energy per experimental cycle. Present experiments are limited to 5 gigajoules.

**4. How does this research support this application?**

It is needed for the development of the next generation fusion experiments.

**5. What research is needed that is not funded?**

- a) Development on extensive utility model capable of representing regional systems.
- b) Research on evaluation of alternative techniques for local energy storage.
- c) Research on problems of utilization of both the grid and the local energy systems simultaneously.

## RESEARCH TOPIC

## MULTI-DIMENSIONAL POWER CONVERSION SYSTEMS

## 1. Brief description of research topic.

This is research related to power systems interaction magnetic components, rectifiers, controls and regulations associated with the next generation fusion devices.

## 2. What are the key research issues?

- a) Mechanical integrity of high-current power transformers.
- b) Precision firing angle control and optimization of power factor.
- c) Research on relative merits on the applications of forced commutation or GTO devices in converter systems.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Present limit of peak power is 75 MVA per converter unit whereas we need 150 MVA. Also we need information about system topology, control and instrumentation techniques to improve the efficiency and reliability of such systems.

## 4. How does this research support this application?

It contributes to viability of the next generation fusion experiments.

## 5. What research is needed that is not funded?

N/A

**RESEARCH TOPIC**  
**SEMICONDUCTORS**

1. Brief description of research topic.

Research on semiconductors for power systems.

2. What are the key research issues?

- a) Bulk physics of power semiconductors.
- b) Edge treatment of the voltage hold-off.
- c) Improvement of switching time and control turn-on and -off capability.
- d) Better packaging for heat transfer.
- e) Improvement of the gate structure.
- f) Phase transition materials for semiconductors.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Present thyatrons have up to 5 kV maximum with current up to 4000 A. Needed about 10 kV and 5000 A with turning-on and -off times about 1-2 microseconds.

4. How does this research support this application?

It will keep to make electrical supply system for fusion reactors more efficient, more reliable, more compact and less expensive.

5. What research is needed that is not funded?

Research on advancing the art of designing and manufacturing rectifiers and thyristors to more fully exploit the potential of power semiconductors.

**Section V**

**Report of the**

**PARTICLE BEAMS COMMITTEE**

**A.K. Hyder and E.P. Muntz, co-chairmen**

# PARTICLE BEAMS

## Committee Members:

A.K. Hyder, E.P. Muntz (co-chairmen),  
T. Burkes, M.T. Buttram, A. Chutjian,  
C. Huddleston, I. Katz, L.C. Lee, K. Whitham

## I. PROBLEM DEFINITION

The participants in the panel on particle beams defined the scope of the subject in terms of a generic particle beam system, shown in Figure 1. In the following discussions the load, pulse forming and storage, and switch three (SW3) are considered (refer to Figure 1).

## II. GENERIC MISSIONS

As a basis for the panel's discussion the performance requirements for particle beam mission scenarios were outlined. The missions reviewed were: endo hi-dose charged particle beams; hi-endo, hi-dose laser guided charged particle beams, hi-endo laser guided charged particle beams for discrimination; exo neutral particle beams for discrimination and system upset; and finally, ion beams for fusion applications.

## III. LOAD

Loads, each having their own requirements, were identified. These included:

- linear induction accelerator
- high current betatron - circular inductive air core
- R.F. quadrupole linac
- diode - secondary emission production

Parameters of importance to these devices are long ( $\mu$ s) pulses, high voltages (MV), at high currents (104A).

The panel identified a number of power conditioning research issues associated with the loads listed above.

- vacuum breakdown in presence of  $\mu$ s pulse length beams (all loads).
- power recovery and management for low power factor circuits (high current betatron, also free electron laser and counter pulse switches).
- RF (linac)
  - solid state devices
  - window flashover
  - high power density
- Beam sources
  - long pulse ( $\mu$ s), high current (kA) and megavolts
  - cathode phenomena, failure and emission
  - negative ion sources

In addition to specifically load related items, a number of load associated systems research issues were identified by the panel. These were:

- Thermal management
  - definition of maximum unit size as limited by internal temperatures
- Fault protection, prevention
  - tolerance
  - EMI/RFI
  - autogenerated radiation
- Reliability
  - system modeling including environmental definition and definitions of component requirements

### PROBLEM DEFINITION

- GENERIC PARTICLE BEAM SYSTEM TO HELP DEFINE RESEARCH ISSUES



- CONSIDERED - LOAD

SW3

PULSE FORM AND STORAGE

FIGURE 1

## PARTICLE BEAMS COMMITTEE

ACCELERATOR ASSOCIATED  
SPECIFIC RESEARCH ISSUES

- Vacuum breakdown in presence of beams for long ( $\mu$ s) pulses (all)
- Materials behaviour at hi-temps and power density (all)
- Power recovery and management for low power factor circuits (H.C.B., FEL, counter pulse switches)
- RF (Linac)
  - solid state devices
  - window flashover
  - hi-power density
- Beam sources
  - long pulse ( $\mu$ sec), hi current (kA), MV
  - cathode phenomena - failure
  - emission
  - negative ion sources
- Thermal management
  - definition of max unit size as limited by internal temperatures
- Fault protection, prevention
  - tolerance
  - EMI/RFI
  - Auto-generated radiation
- Reliability
  - system modeling including environment definition and definition of component requirements

## IV. SWITCHES

The panel considered the following switch device types: magnetics, spark gaps, thyratrons; and photoconductive/solid state. Switch requirements were considered with the following self-consistent parameters considered appropriate:

Closing Switches		Opening Switches	
$\mu$ s	10's ns	$\mu$ s	$\mu$ s
MV	MV	MV	kV
10 Hz	100 kHz	10's kA	MA
kA	10's kA	10's Hz	10's Hz

The panel decided to not consider opening switches as these appeared more appropriate to the rail gun community.

Research issues were identified with each of the device classes.

- Magnetics
  - high voltage transformers
  - saturable reactor switches
  - lightweight iron
- Solid state (mJ, ns trigger)
  - high temperatures
  - radiation resistors
  - monolithic (no contacts) configurations
  - photoconductor physics
  - flashover resistance
- Spark gaps thyratrons
  - studies of the gaseous electronics to improve quantitative understanding
  - cross-sections required
  - electrode phenomena
  - space environment issues - phenomena related to interaction of space environment and high voltage exposed components

## V. STORAGE AND PULSE FORMING

The panel identified the following research issues associated with this area. They assumed rotating machinery was outside of the panels charter.

- Solid and liquid dielectric lines (dielectric constant  $\sim 1000$ 's)
- Ceramics, chemical double layers, composites and other capacitors and batteries.

VI. BROADLY BASED RESEARCH  
ISSUES

The panel found that a few research issues were important to a large proportion of the subjects addressed by the panel. These are considered to be areas that would yield widely useful results and are thus suitable subjects for high priority research efforts. The topics in this category identified by the panel were:

- Effects of space and near space environment
  - dielectric damage due to energetic particles
  - dielectric damage due to O atoms
  - charging characteristics
  - micro-g effects on switches and other components where bulk material motion is involved

## PARTICLE BEAMS COMMITTEE

- control of large structures, impact on power systems
- minimization of magnetic induction force on structure
- need for a suitable space environment simulator
- Materials
  - hi e/hi breakdown strength
  - hi resistivity
  - low loss
  - radiation resistant
  - new built and composite materials
  - surface modification and protection techniques
  - hi temperature
  - heterogeneous interfaces

**VII. HIGH LEVERAGE RESEARCH ISSUES**

Finally, the following research issues were considered to have the largest potential for high pay-off in terms of research funding:

- Ground based simulation of O atom, charging, radiation and outgassing effects on power conditioning components
- Unique dielectrics -hi T, hi e, need to understand physics
- Solid state devices - fast, hi T, hi power

**RESEARCH TOPIC**  
**THERMAL MANAGEMENT**

1. Brief description of research topic.

A systems issue of thermal management as modular components is designed to accommodate larger power densities. At some point the thermal management problem will limit the power density of the module.

2. What are the key research issues?

Behavior of materials and components at high temp and high power densities. Special interest is on high temp dielectrics.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Systems viewpoint studies are needed to fix module size and module power densities. The thermal load issues can then be addressed. It looks as if volume size will be dominated not by power density but by thermal load.

4. How does this research support this application?

It is generic to all aspects of all systems in all scenarios.

**RESEARCH TOPIC**  
**SOLID STATE PHYSICS**

1. Brief description of research topic.

Solid state devices, especially solid state (SS) switches, will be required throughout the power conditioning train. Research is needed in the behavior of innovative SS materials (e.g. III-V compounds) in the space environment.

2. What are the key research issues?

- a) Availability of mJ, ns compact laser triggers.
- b) High temperature radiation resistant, self annealing SS switches and electronics.
- c) Monolithic devices which do not suffer from contact resistances.
- d) Improved flashover resistance of SS materials.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

New materials are required. III-V compounds offer hope. The defect densities must be reduced by 2-3 orders of magnitude. Over 90% of the heat is generated at the contact point. Work on contact resistance must be done.

4. How does this research support this application?

Solid state devices hold the key to height-volume-temp-reliability etc. solution to space-based power problems for accelerator of power, switching, etc.

## RESEARCH TOPIC

## FAULT PROTECTION AND PREVENTION

## 1. Brief description of research topic.

Power systems will operate in a remote and hostile environment. They must be designed to survive autonomously and to be tolerant of faults and failures, to recognize, compensate and isolate component failure in the power system and power control computers.

## 2. What are the key research issues?

- a) Fault tolerant computer architecture and software.
- b) EMI/RFI isolation of critical components.
- c) Internal and external radiation resistant materials.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

How much control is needed? Can redundancy replace the need for fault-tolerance diagnostics? What RFI/EMI/radiation levels will be present? How resistant are present devices to these levels?

## 4. How does this research support this application?

No system will fly without a fault protection/fault prevention/fault tolerant design. It cannot be retrofitted. It must be engineered from the outset.

## RESEARCH TOPIC

## RELIABILITY - COMPONENT CHARACTERIZATION

## 1. Brief description of research topic.

Major components and subsystems need to be characterized to assure that they meet reliability standards. This will be done by accelerated testing of component samples at conditions approximating actual environment, and by establishing reasonable confidence limits.

## 2. What are the key research issues?

Build test stands for major components and test in quantities sufficient to establish life data.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Life data on new components does not currently exist.

## 4. How does this research support this application?

Establishing means for obtaining this data.

## 5. What research is needed that is not funded?

N/A

## 6. Comments:

Many system components will be standard and data exists or can be derived from existing experience. This testing is not for this category of items. It is necessary for new, high leverage, highly stressed components that will exist in each system.

RESEARCH TOPIC  
RELIABILITY - MODEL

1. Brief description of research topic.

Overall system reliability in a given environment must be defined. A model of the given systems must then be generated with sufficient detail to establish the definition of each major subsystem and component. From this model and overall system requirements, subsystem and major component reliability specifications can be drawn. This is required for setting goals for research and development and for trading off design approaches. This model needs to be maintained during design cycle.

2. What are the key research issues?

- a) System definition
- b) Environment definition
- c) Reliability requirements
- d) Derived component requirements

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Component life in operating environment.

4. How does this research support this application?

Develops model to relate system reliability and environment to component life.

5. What research is needed that is not funded?

N/A

6. Comments:

Space systems require careful attention to reliability. Component requirements need to be defined from a realistic system model. This work needs to be done in the initial stages of a program, and maintained to keep models current and to feed implications back to component designers.

## RESEARCH TOPIC

**NEUTRALIZATION OF SPACECRAFT  
WHICH EMIT CHARGED PARTICLE BEAMS**

1. Brief description of research topic.
  - a) Develop models of both passive and active neutralization of spacecraft which emit charged particle (electron) beams in the MeV, 1-100 kA, s regime.
  - b) Perform experiments to test key elements of the model.
2. What are the key research issues?
  - a) Time dependence of sheath formation.
  - b) Surface interaction (including illumination + X-ray generation) of returning electrons.
  - c) Relaxation of local plasma after a pulse.
  - d) Neutralization using plasma sources.
3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?
  - a) Collected current as a function of time and orbital parameters.
  - b) Energy distribution of electrons on surfaces, photo and X-ray cross sections.
  - c) Time dependent theory of neutralization using plasma sources.
  - d) Present theories for KeV, 1 amp., steady state beams.
  - e) No time dependent theory of plasma source as neutralizer - some lab results.
5. How does this research support this application?

Vehicle charging will cause intense illumination and fields strong enough to modify particle trajectories -- also X-rays will be generated.

**RESEARCH TOPIC**  
**ELECTRICAL ENERGY STORAGE**

1. Brief description of research topic.

The storage media for the required pulse forming to drive the load and charging pulse storage.

2. What are the key research issues?

- a) New materials needed, ferroelectric materials,  $r > 1000$ , for capacitors and transmission lines, ceramics, composites.
- b) New batteries, chemical double layer, capacitor, low loss, high energy density.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Energy density  $> 100$  joules/gram 1 Kv- /gram desired
- b) Present?  $\sim 10$  joules/gram

4. How does this research support this application?

Would allow design to simpler, lighter weight system to drive accelerators and/or general component upgrade for inverters etc.

5. What research is needed that is not funded?

More physics, material characterization for large area, large volume casting, etc.

6. Comments:

The capability of making these batteries, and pulse forming lines would have an immediate and broad impact on the engineering of power conditioning pulse power systems important to SDI.

## RESEARCH TOPIC

## RF SOURCES

1. Brief description of research topic.

The generation of the required RF generators to drive linac type accelerators.

2. What are the key research issues?

Present sources are relatively low power (600 Kw. average), large and heavy - Klystrons, etc.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Need - single sources, capable of  $\sim$  5 MW Average - lightweight.
- b) Have  $\sim$ 600 KW, 100's of lbs. units

4. How does this research support this application?

Would reduce weight and volume.

5. What research is needed that is not funded?

- a) Solid state RF sources at very high average power.
- b) High power RF windows.
- c) High power density devices.

6. Comments:

- a) Present sources are limited by the required cavity size, magnetic focusing, etc. and the power density capable of the required RF window.
- b) Solid sources offer potential of lightweight, lower voltage operation and probably avoid the window requirements.

RESEARCH TOPIC  
SPARK GAPS AND THYRATRONS

1. Brief description of research topic.

Measurement of electron collision and attachment cross sections for the gas components of the spark gap or thyatron.

2. What are the key research issues?

- a) For spark gaps - thermal attachment cross sections of  $F_2$ , prefluorinated carbon components,  $SF_6$ .
- b) For thyratrons - metastable (electronic and vibrational)  $H_2$  cross sections, and e-molecular, atomic ion cross sections leading to photon emission from the switch.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Thermal ( $< 0.1$  eV) attachment data.
- b) e-excitation cross sections from metastable (electronic, vibrational) molecules ( $H_2$ ,  $N_2$ ) and atoms (rare gas).
- c) e-excitation cross sections in molecular ions ( $H_2^+$ ,  $N_2^+$ ) and atoms (rare gas+).

4. How does this research support this application?

It supplies basic data in the form of cross section 's, rather than rate constants, to model the plasma of the switch or thyatron.

5. What research is needed that is not funded?

- a) cross section 's for electron excitation and attachment from metastable levels.
- b) cross section 's for e-ion (molecular or atom, singly charged) excitation leading to photon emission.

6. Comments:

- a) Cross sections for excitation out of, and attachment to, vibrationally-excited  $H_2$  are also needed to understand the behavior of the volume H- source.
- b) Parallel work in e-ion collisions in other DoE and NASA labs should be identified.

## RESEARCH TOPIC

## EXCITED OXYGEN-SPACECRAFT INTERACTION

1. Brief description of research topic.
  - a) Interaction of ground state oxygen atoms [ $O(^3P)$ ] with spacecraft (s/c) structures.
  - b) Measurement of spacecraft charging by electron, photon-induced secondary electron emission.
2. What are the key research issues?
  - a) How do windows, mirrors, lenses and surfaces degrade by oxidation? What is the lifetime of an aluminum (for example) mirror at  $O(^3P)$  fluxes of  $10^{12}$ - $10^{14}/\text{cm}^2 \text{ s}$ ?
  - b) What are the secondary electron emission coefficients for the s/c materials used?
3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?
  - a) Effect of  $O(^3P)$  on s/c lifetime: rate of mirror reflectivity or window transmission loss vs dosage of  $O(^3P)$ .
  - b) Secondary electron emission coefficients for conductors, insulators, and composites are needed.
4. How does this research support this application?
  - a) Materials can be designed or tested to withstand oxidation.
  - b) S/c components can be tested in the laboratory.
  - c) Secondary electron emission coefficients can be folded into SCATH or POLAR codes to model s/c charging.
5. What research is needed that is not funded?
  - a) A source of high flux ( $10^{12}$ - $10^{14}/\text{cm}^2\text{-s}$ ), high energy (3-10 eV) ground state [ $O(^3P)$ ] oxygen atoms is needed.
  - b) Techniques for measuring secondary electron emission coefficients in conductors, insulators and composites is needed.

## 6. Comments:

The only O-atom source available is the so-called "laser blow-off" source which produces a high density of unwanted excited states, and beam-energy widths that are too broad.

## RESEARCH TOPIC

## NEUTRAL GAS AND METEOROID/DEBRIS ENVIRONMENT

1. Brief description of research topic.

Collect data and model neutral gas and meteoroid/debris environment for pulsed power spacecraft, including models of outgassing and thrusters.

2. What are the key research issues?

Rates and mechanisms for outgassing of dielectrics integration of dynamic control, heating and shock on the neutral gas environment.

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Rates - particle densities for materials used in pulsed power, as functions of temperature and time, in orbit collision probabilities for various orbits.

4. How does this research support this application?

- a) Neutral gases affect breakdown thresholds and can contaminate other systems.
- b) Very large, very long life systems need collision probability information for design.

## RESEARCH TOPIC

**PULSED POWER IN THE MICROGRAVITY ENVIRONMENT**

## 1. Brief description of research topic.

Examine and model effects on Pulsed Power components and systems of operation in the zero-g orbital environment.

## 2. What are the key research issues?

- a) Switch and load characteristics and reproductivity in zero-g due to floating droplets, sputtering erosion debris and convection effects.
- b) Control of system dynamics due to shocks, loads and magnetic torques.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) What phenomena will affect switch and load performance - space high voltage systems which failed include ion thruster (spattering short) and electron accelerates (bolt floated loose and shorted H ).
- b) No anchor for systems - currents huge compared with point systems.

## 4. How does this research support this application?

Reliability and pointing require prevention of high voltage shorting and large dynamic motion.

## RESEARCH TOPIC

**SPACE PLASMA INTERACTION  
WITH VERY HIGH VOLTAGE SYSTEMS**

## 1. Brief description of research topic.

Perform lab experiments, develop simulation models and design guidelines which describe the interactions of the natural and spacecraft generated plasmas with high voltage components and systems.

## 2. What are the key research issues?

- a) Plasma induced arcing.
- b) Parasitic currents and resultant power losses.
- c) Photoelectron transport along surfaces - conduction and cascade.
- d) Material sputtering due to ion bombardment.
- e) High energy electron deposition in dielectrics.
- f) Plasma sheath dynamics during pulse.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Insulation requirements (present limits < 1 kV).
- b) Currents in HV sheaths.
- c) Photoelectron dynamics (e.g. effective conductivities in presence of large fields - present limit is for 1000 volts).
- d) Transient voltage phenomena (all previous steady state).

## 4. How does this research support this application?

High voltages are key element of pulsed power in space present power systems are limited to ~100 volts due to plasma effects.

## RESEARCH TOPIC

## BEAM SOURCES

1. Brief description of research topic.

Cathode and ion sources.

2. What are the key research issues?

	Electrons	Ions
Long pulse length	1-10 s	CW
High Current	~10 kA	> 100 mA
Emittance	100 cm. mrad	0.1 cm. mrad
High voltage	MV	MV
Rep. Rate	10 k Hz	Hz

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Reaction chemistry for ion sources.
- b) Emittance diagnostics
- c) Non-perturbing diagnostics for E,I, etc.

4. How does this research support this application?

Allows production and validation of particle beams with desired parameters.

5. What research is needed that is not funded?

Radiative diagnostics; e.g. transition radiation, interferometry, UV sources, long-pulse diodes.

6. Comments:

Research in gas chemistry would benefit gas switches.

## RESEARCH TOPICS

## MATERIALS FOR ENERGY-STORAGE DEVICES (CAPACITORS)

## 1. Brief description of research topic.

Towards developing high energy density (high power, high voltage, lightweight high repetition rate, radiation resistant, high reliability, long-life capacitors).

## 2. What are the key research issues?

- a) Materials (solids, liquids, films, impregnants)
  - Developing high R, high dielectric strength, low loss, low-density, radiation resistant, thermally-stable and chemically compatible materials.
- b) Engineering
  - Pretreatment, impregnation, and winding techniques.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Morphology
- b) Surface properties
- c) Additives
- d) Life modeling and failure analysis under multi-stress environment (electrical, thermal, mechanical, radiation).
- e) Molecular chemistry

Required:  $k > 20$ , breakdown intrinsic  
 $\tan \sim 10^{-4}$ , lightweight,  $> 10^8$  rad

Present limits: films  $k \sim 14$  (surface problems - films 'fail' at  $\sim 10^7 - 10^8$  rads)  
liquids  $R < 10$  (no radiation data available on liquids)

## 4. How does this research support this application?

Better understanding of material properties, aging and failure analysis under multistress environment will give very high reliabilities.

## 5. What research is needed that is not funded?

- a) Life modeling under multi-stress environment.
- b) Morphology
- c) Surface properties of films
- d) Molecular chemistry (high R, low loss, lightweight).

## RESEARCH TOPIC

## VACUUM BREAKDOWN IN BEAM SOURCES

## 1. Brief description of research topic.

Vacuum breakdown in microsecond/megavolt beam sources.

- a) Where does the material required to turn a vacuum into a vacuum arc generated?
- b) How does it get ionized?
- c) How can incipient breakdown be detected and aborted?

## 2. What are the key research issues?

- a) What is the composition and temperature of cathode plasmas/neutral?
- b) Why do they form in hot cathode guns? Can they be controlled in cold cathode guns?
- c) What leads to anode ion emission?
- d) Can the electron/ion/neutral flows be observed experimentally?

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Microsecond voltage/current pulses.
- b) Hundreds of kilovolts to megavolts.
- c) Cold and hot cathodes.
- d)  $10^{-4}$  to  $10^{-8}$  (?) Torr
- e)  $\sim 10^3$  AMP,  $\sim 10$  A/cm<sup>2</sup> at the cathode.

## 4. How does this research support this application?

Vacuum breakdown and incipient BKON (impedance collapse) are two primary constraints on the design of pulsed power for driving beam loads.

## 5. What research is needed that is not funded?

- a) Time resolved diagnostics of the flow of matter (and photons) in a beam source.
- b) Explore dynamics of cathode plasmas and their composition and neutrals component.
- c) Explore anode plasma formation.
- d) Explore dispersal of pre-vacuum arc plasmas when voltage and/or current are reduced.

## RESEARCH TOPIC

## MAGNETICS

## 1. Brief description of research topic.

Magnetics include cores for transformers and induction accelerators and saturable inductor switches.

## 2. What are the key research issues?

## a) Need:

- i) highest ( $H = B$ )
- ii) fastest switching (saturation time)
- iii) highest  $B$
- iv) lowest loss (high resistivity)
- v) low density - simultaneously.

## b) Need: high dielectric strength to reach MV levels.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

- a) Need: Large  $B$  ( $>1$  TESLA?), low density material (if possible!)
- b) Need: High (1000 ?) at high frequency ( $>100$  MHz).
- c) Need: Fields  $\gg 100$  KV/cm (e.g. new dielectric system) in wound cores.

## 4. How does this research support this application?

- a) Saturable magnetics are the leading high rep rate, HV switching option, higher voltages in lighter systems are required/desirable.
- b) Better materials would allow improved pulse transformers allowing some pulse forming to be done at low voltage, relieving HV insulation constraints.

## 5. What research is needed that is not funded?

- a) Develop better ferrites or equivalent.
- b) Develop better fabrication techniques for wound systems.
- c) Develop innovative transformer designs.
- d) Detailed studies of saturation phenomena.
- e) Optimize shock loaded ferrite pulse sharpeners (or equivalent).

## RESEARCH TOPIC

## GAS CHEMISTRY AND ENGINEERING

## 1. Brief description of research topic.

- a) Fluorocarbon gas chemistry - to determine the electron attachment and gas dielectric properties of various fluorocarbons in high pressure buffer gases.
- b) Photoabsorption and photoionization cross sections of gases to be used in gaseous switches.
- c) Electron-attachment and electron-ionization rate constants of gases and transient radicals.
- d) Gas engineering - to find gas mixtures that have desirable properties for discharge switches.

## 2. What are the key research issues?

Each discharge switch requires different electron transport parameters (such as electron drift velocity, electron-attachment and electron-ionization rates) and photoexcitation processes in the vacuum ultraviolet region. In order to satisfy the specific requirement of a discharge switch gas mixtures such as fluorocarbon or electromagnetic gases in high pressure buffer gas are needed. It is necessary to have a data bank that can provide the gaseous properties needed.

## 3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

The electron attachment rate constants of electronegative gases (such as  $\text{H}_2\text{O}$ ,  $\text{N}_2\text{O}$ ,  $\text{SO}_2$ ,  $\text{CS}_2$ ,  $\text{OSC}$ ,  $\text{HCl}$ ,  $\text{Cl}_2$ ,  $\text{F}_2$ ,  $\text{NH}_3$ ,  $\text{SOCl}_2$ , etc.) and fluorocarbons (such as  $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ ,  $\text{C}_3\text{F}_8$ ,  $\text{CF}_3\text{Cl}$ , etc.) in various high pressure buffer gases (such as  $\text{Ar}$ ,  $\text{N}_2$ ,  $\text{CH}_4$ , etc.) are needed. The multi-photoionization coefficients of molecules that have high ionization efficiencies need to be measured. The data are not complex at this moment.

## 4. How does this research support this application?

The data bank will provide information for designing suitable discharge switches for specific applications. For example, a discharge switch can be turned on by laser using molecules that have high multiphoton coefficient. And the switch can be quickly turned off by electron attachment to electronegative gases. The transient species that have high electron attachment rate constants can be produced by laser photodissociation process.

## 5. Comments:

For successful designs of various gaseous discharge switches, data banks for photon and electron interaction properties of various gases, radicals, and gas mixtures are needed.

RESEARCH TOPIC  
SWITCHES (SPARK GAPS)

1. Brief description of research topic.

Towards developing high repetition rate, high power, high reliability, long life gas filled spark gaps (switches).

2. What are the key research issues?

- a) Gas recovery
- b) Gas decomposition                      under high repetition
- c) High withstand voltage                rates (~ 10 KHz)
- d) Turn-on time

3. Specifically what numbers and/or information and/or parameters are needed? What are the present limits or boundaries?

Effect of gas decomposition with aging (at high repetition rate and high power) on turn-on and turn-off times.

4. How does this research support this application?

Reliability in 'firing' of load.

Required:        <10 sec. recovery  
                    <1 nsec turn-on at 10 KHz

Present limits: not known

5. What research is needed that is not funded?

Same as No. 4.

6. Comments:

This is only one of the few research issues we are aware of in gas-filled spark gaps, there are more.

## LIST OF PARTICIPANTS

Ray Askew - Nuclear Science Center, Auburn University  
 John R. Bayless - Pulse Sciences, Inc.  
 Tom R. Burkes - Texas Tech University  
 Andrew H. Bushnell - Maxwell Laboratories  
 Malcolm T. Buttram - Sandia National Laboratories  
 W. Byszewski - GTE Laboratories  
 Loucas Christophorou - Oak Ridge National Laboratory  
 Ara Chutjian - Jet Propulsion Laboratory  
 James Crissey - W.J. Schafer Associates  
 Robert DeWitt - Naval Surface Weapons Center  
 Roger A. Dougal - University of South Carolina  
 George Frazier - Physics International Co.  
 Henry Grunwald - ITT, Electron Tube Division  
 Arthur H. Guenther - Air Force Weapons Laboratory  
 Martin A. Gundersen - University of Southern California  
 Lynn Hatfield - Texas Tech University  
 Milton W. Heyne - Hughes Research Laboratory  
 C.M. Huddleston - Naval Surface Weapons Center  
 Daniel Huttar - Plasma Physics Laboratory, Princeton University  
 Anthony Hyder, Jr. - Auburn University  
 Jay Hyman - Hughes Research Laboratory  
 C. Randol Jones - Los Alamos National Laboratory  
 Ira Katz - S-cubed  
 Hans Kuehl - University of Southern California  
 Joseph A. Kunc - University of Southern California  
 Erich E. Kunhardt - Polytechnic Institute of New York  
 Mark Kushner - Spectra Technology  
 Javaid R. Laghari - University of Buffalo, State University of New York  
 James E. Lawler - University of Wisconsin-Madison  
 Long Chi Lee - San Diego State University  
 Donald C. Lorents - SRI International  
 Phillip N. Mace - W.J. Schafer Associates Inc.  
 Glen McDuff - Los Alamos National Laboratory  
 Eric Philip Muntz - University of Southern California  
 Arati Prabhakar - Congressional Office of Science and Technology Assessment  
 Allen Ramrus - Maxwell Laboratories  
 Peter Rock - G.A. Technologies  
 Frank Rose - Auburn University  
 Gerhard Schaefer - Texas Tech University  
 Sol Schneider - Electronic Technology & Device Lab, U.S. Army ERADCOM  
 Karl H. Schoenbach - Old Dominion University  
 Robert W. Schumacher - Hughes Research Laboratory  
 Sidney Singer - Office of Science & Technology Policy  
 David Skatrud - U.S. Army Research Office  
 Bruce Smith - Air Force Office of Scientific Research  
 William G. Spitzer - University of Southern California  
 Santosh Srivastava - Jet Propulsion Laboratory

Joe V. Stover - Ground Systems Group, Hughes Aircraft Company  
Chia Thio - Westinghouse R&D Center  
David V. Turnquist - Impulse Engineering Inc.  
Richard Verga - Strategic Defense Initiative Office  
Frazer Williams - University of Nebraska-Lincoln  
Kenneth Whitham - Maxwell Laboratories

# AGENDA

December 3 and 4, 1985

**Tuesday, December 3, 1985**

- 8:00      **Opening of Workshop: Welcome and Introductory Remarks**  
M. Gundersen, C.R. Jones, and W.G. Spitzer
- 8:45      **A Historical Overview of Semiconductor Device Development: A Partnership between Research and Results**  
W.G. Spitzer, USC Vice Provost for Research
- 9:15      **SDIO Power Conditioning Issues**  
R. Verga, Strategic Defense Initiative Office  
L. Caveny, Strategic Defense Initiative Office  
F. Rose, Auburn University
- 10:00      **Break**
- 10:15      **Unusual Prime Power Generators for Transient Applications**  
S. Singer, White House Office of Science and Technology
- 11:00      **Limitations in Power Conditioning**  
T.R. Burkes, Texas Tech University
- 11:30      **Committee Introduction and Charge**

Afternoon Session

- 1:00-5:00      **Committee Meetings**  
Meeting rooms for committees will be posted in Gerontology Lobby

**Wednesday, December 4, 1985**

- 8:30-12:00      **Committee Meetings**

Afternoon Session: Gerontology Auditorium

- 1:00-4:00      **Committee Reports**
- 4:00-4:15      **Closing Remarks and End of Workshop**

END

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